X-ray Nondestructive Characterization of Mesoscale (mm extent with μm features) Objects

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at

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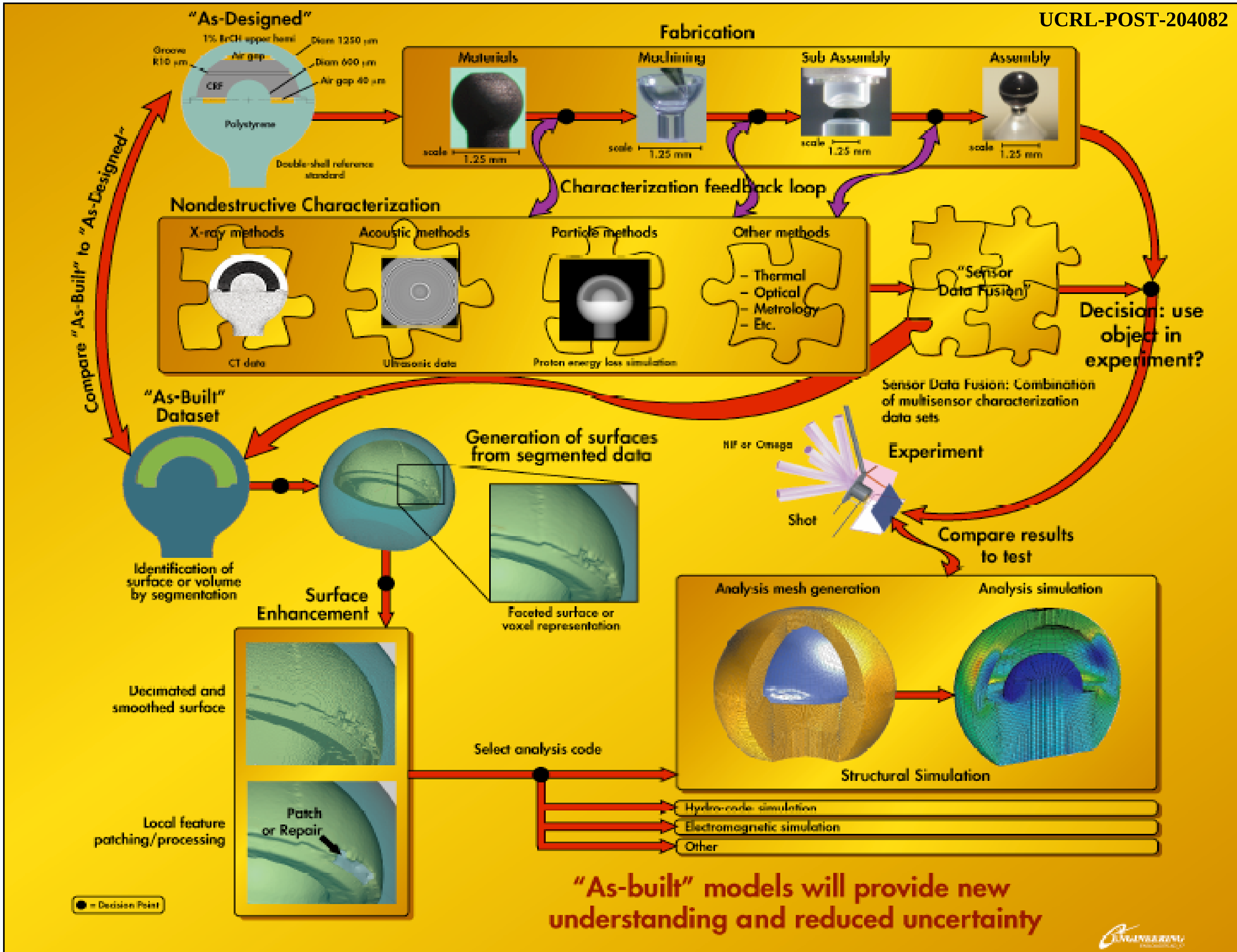
UCRL-PRES-206247

Using characterization to close the loop from design, through fabrication and experiment to simulations-ABM



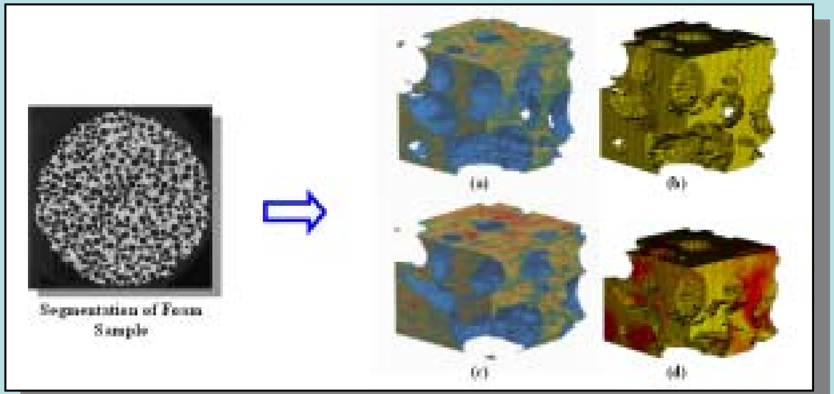
Industrial x-ray CT nondestructively evaluates materials, components, and assemblies

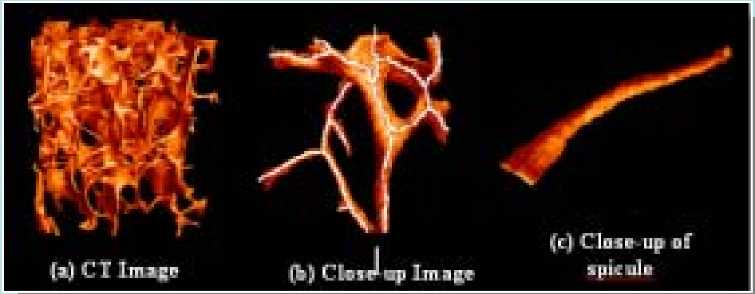
- **Inspection – Structural integrity using attenuation measurements**
  - — Uniformity (homogeneity/inhomogeneity, gradients, etc.)
  - — Porosity
  - — Defect detection (voids, cracks, inclusions, etc.)
  - — Dimensions (size, shape, etc.)
  - — Assembly verification
- **Characterization – Quantitative physical properties per voxel using multi-energy attenuation measurements**
  - — Absolute volumetric density (g/cm^3)
  - — Effective atomic number (Z)
  - — Component weight fraction (%)
  - — Radioactivity (Ci)
  - — Electron density (e$^-$/m^3)

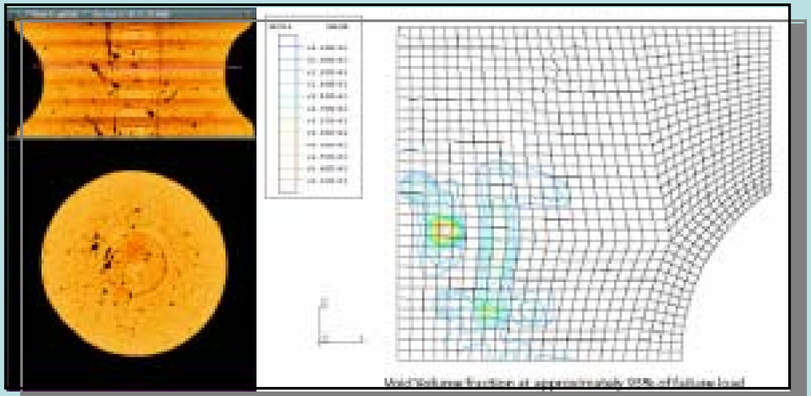
To meet these evaluation objectives requires artifact-free quantitative data

NDC applications at LLNL range from small to large objects and require a range of x-ray imaging systems

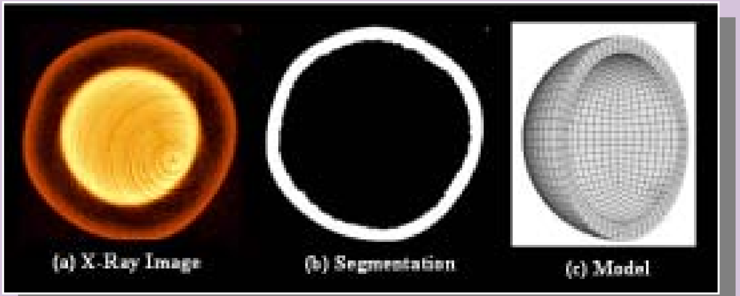
XTM at SLAC



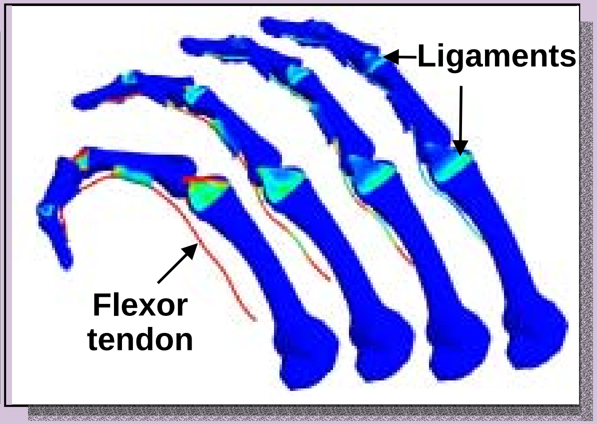




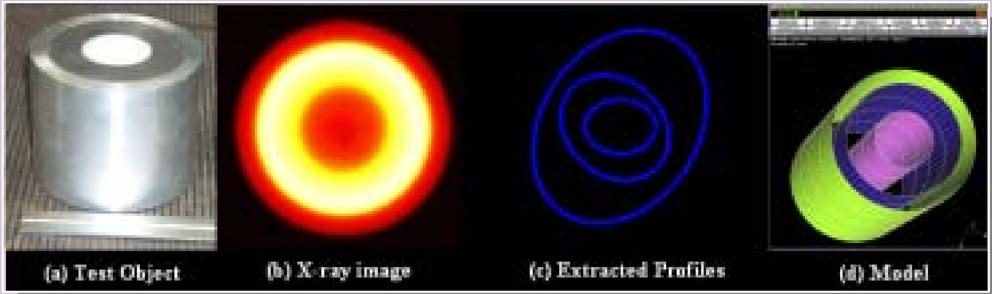
KCAT at LLNL



LCAT at LLNL



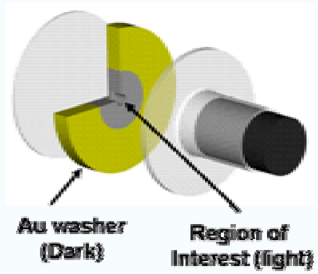
HECAT at LLNL



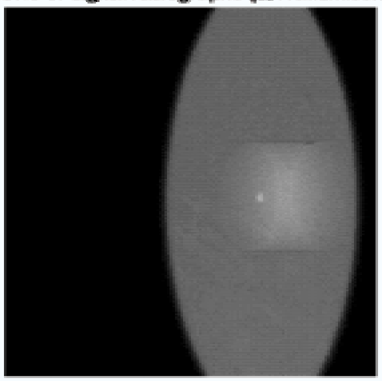
Current emphasis is on mesoscale objects of strategic importance to Lawrence Livermore National Laboratory

Program	Applications
ICF	DT layer in Be shell
HED	Planar, 2D hydro Planar features Rad. Transport Convergent hydro
DOD	Low-collat. HE Shock-dissip. fuels Enhanced-blast HE Detonators, etc.
NAI	Adv. communications Sensor modules
WFOs	NASA, KAPL, ORNL, and others TBD…

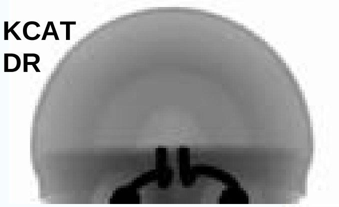
Schematic of 2D hydro target



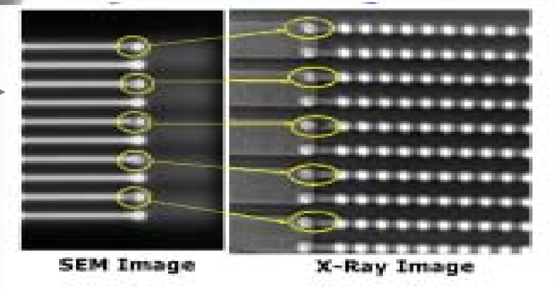
Movie of digital radiographs (%Transmission)



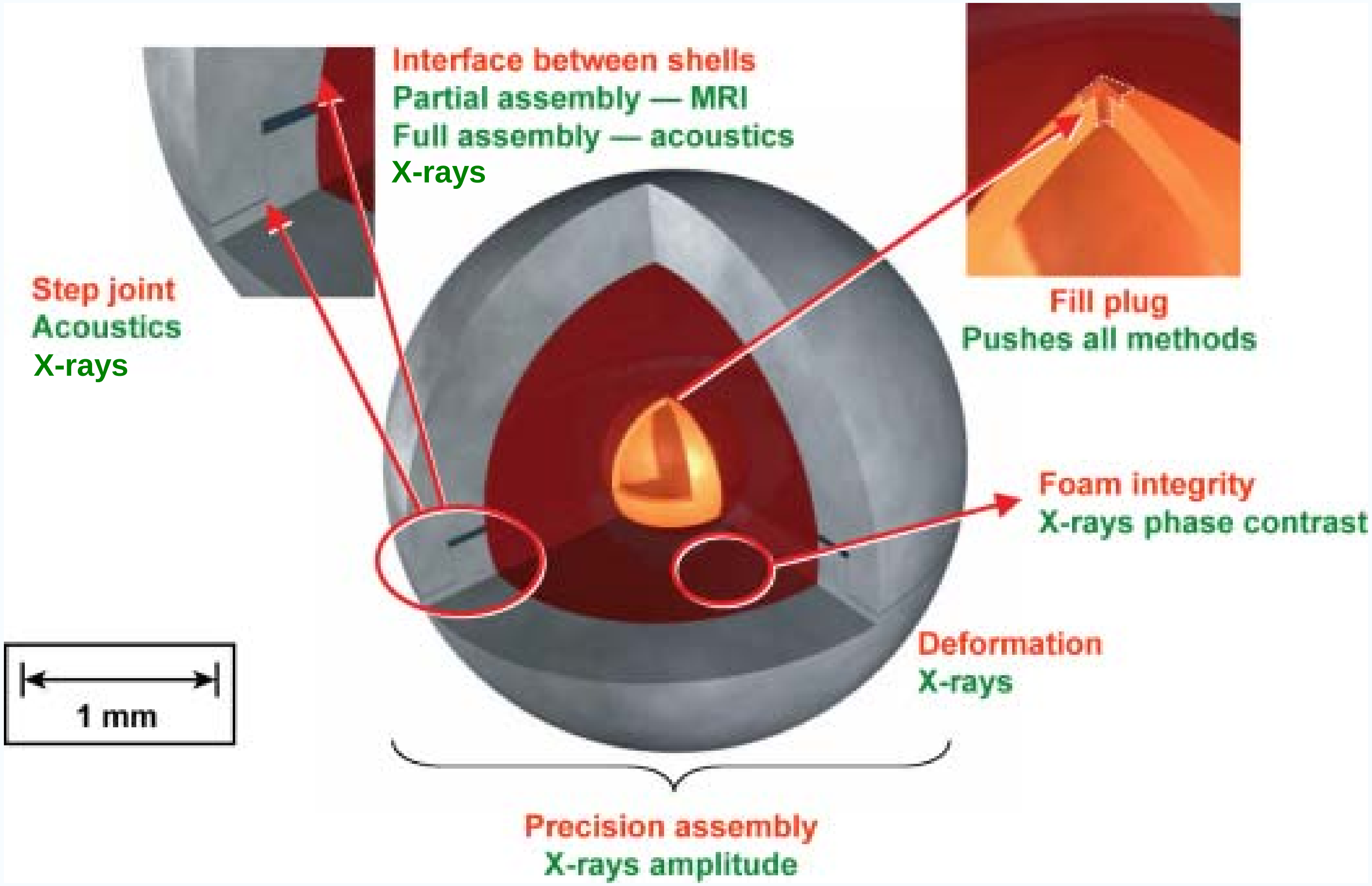
Xradia DR data



Xradia CT data

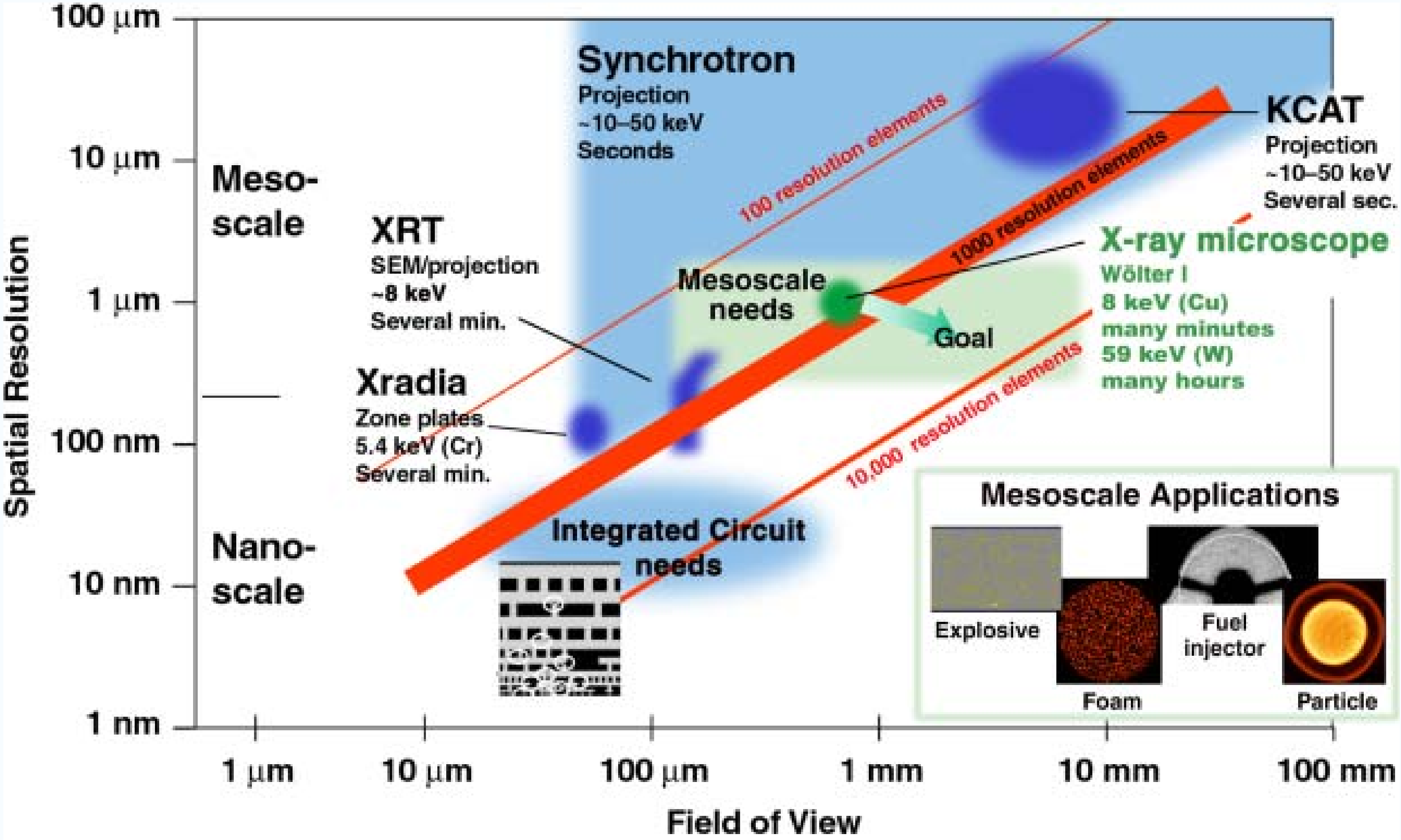


The convergent hydrodynamic or double shell design pushes fabrication and nondestructive characterization capabilities



The nondestructive characterization requirement is 3D imaging at better than a micrometer spatial resolution

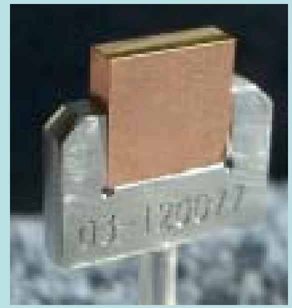
The goal is micrometer resolution over mm FOV at very high collection efficiency to maximize phase and amplitude contrast for mesoscale objects



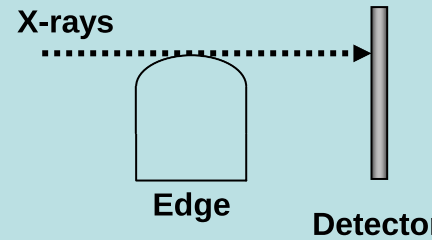
Reference standards will be used to benchmark these possible x-ray NDC candidates

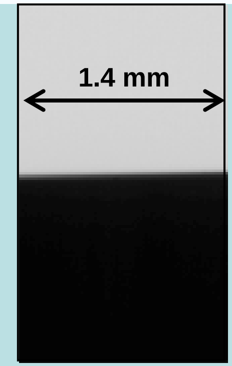
Reference standards are useful in the validation of the simulation and object recovery methods

- Radiographic or 2D standards
  - Ta edge
  - Au coated Cu Edge
  - Plastic rod
  - Multiple material step wedge preliminary design completed



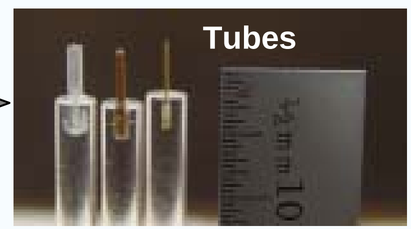
Au coated Cu Edge
10 mm X 10 mm X 3 mm



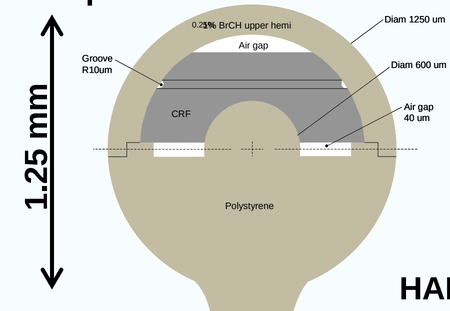


CCAT DR of edge

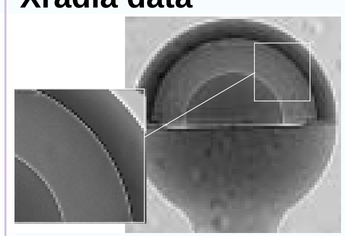
- Tomographic or 3D standards
  - Plastic rod
  - LDPE, Cu and Au tubes
  - Ethylene glycol solution in plastic tube
  - LX17 pellet
  - Cylindrical reference standard
  - Spherical reference standard



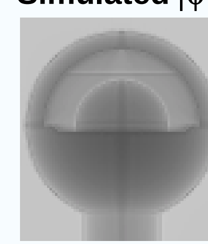
Spherical reference standard



Xradia data

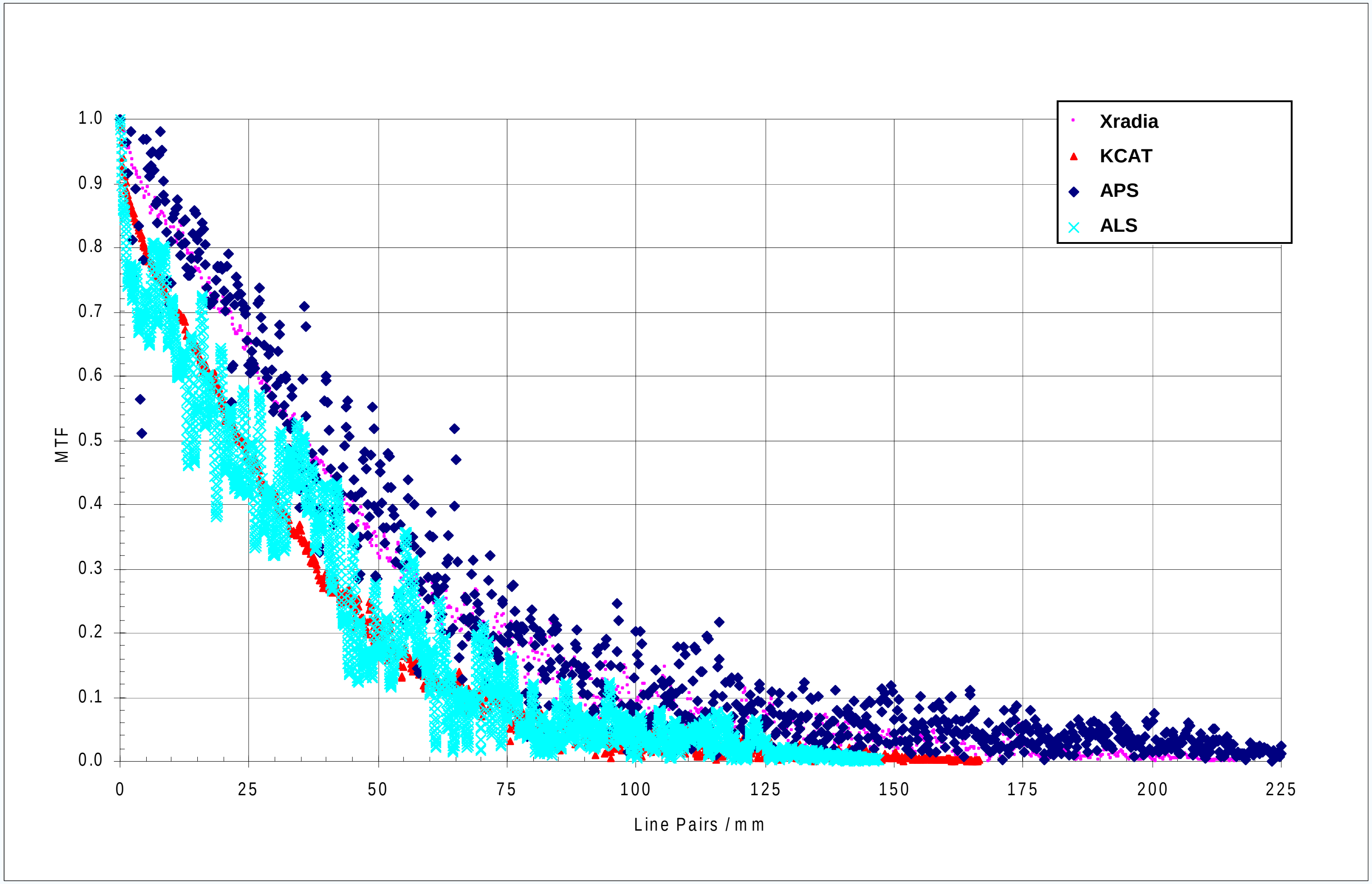


HADES
Simulated $|\psi|^2$

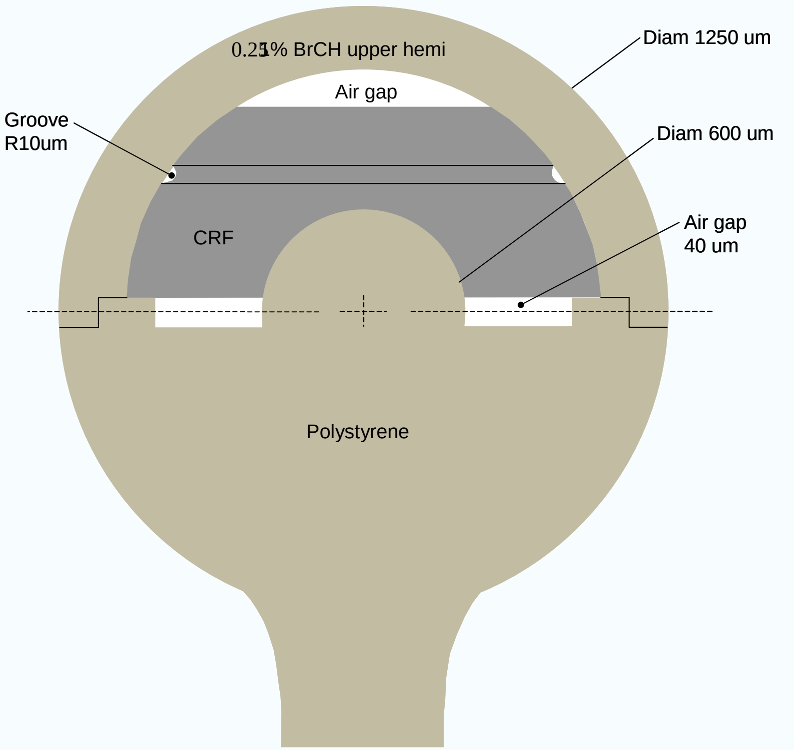


We are using available x-ray DR/CT systems

Comparison of Ta edge MTFs for KCAT, Xradia, ALS and APS x-ray imaging systems

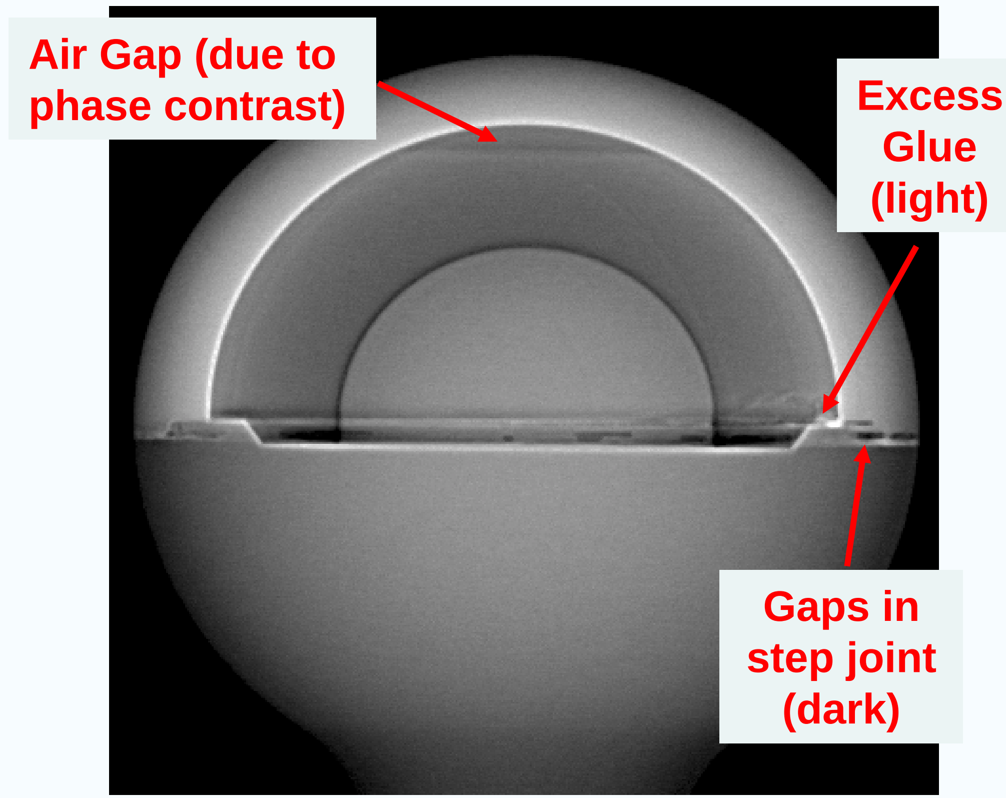


KCAT digital projections of a double-shell spherical reference standard reveals several key features



KCAT

Attenuation image (ln I_0/I)

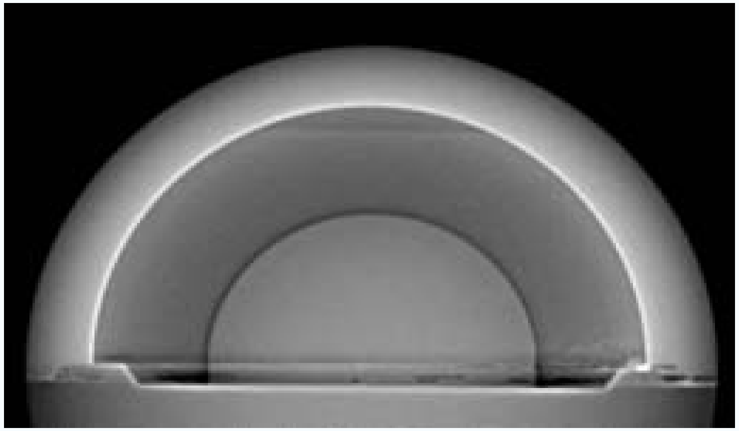


<u>Spherical reference standard</u>:

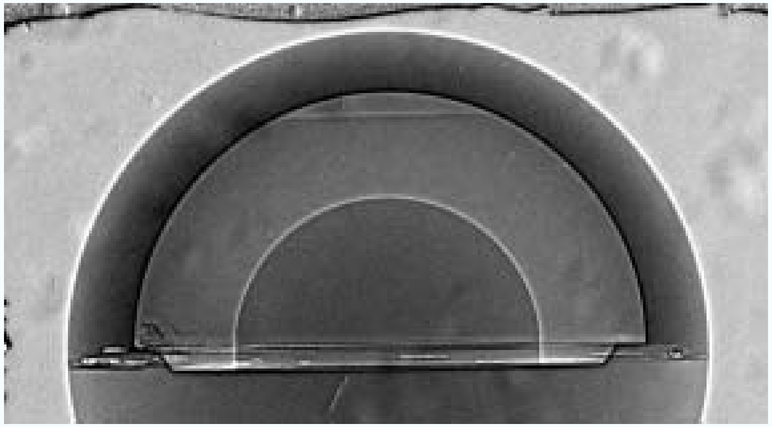
- **Polystyrene and low-density foam**
- **Features are machinable and measurable**
- **Simulated internal capsule that is dimensionally stable**
- **Has air gaps, defects, step joint and two materials for NDE**

We have acquired data on the spherical reference standard using KCAT, Xradia, APS and ALS

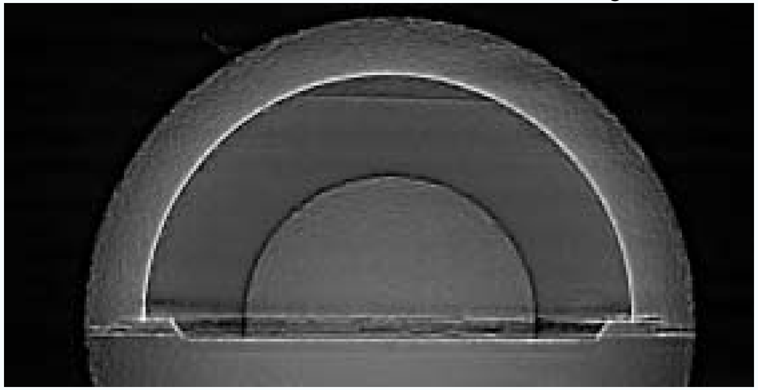
KCAT
Attenuation image ($\ln I_0/I$)



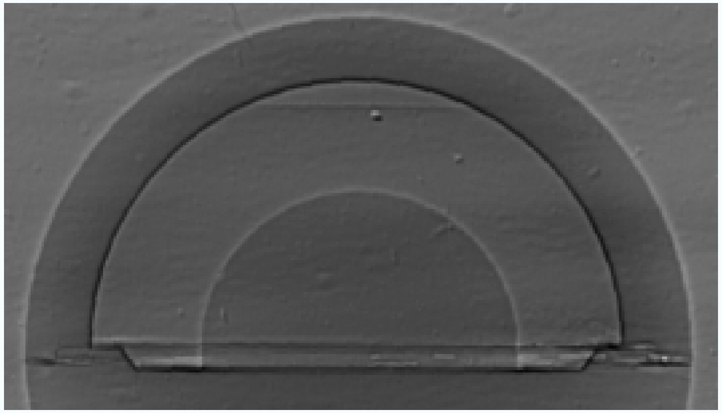
XRADIA
Transmission image (I/I_0)



ALS
Attenuation image ($\ln I_0/I$)

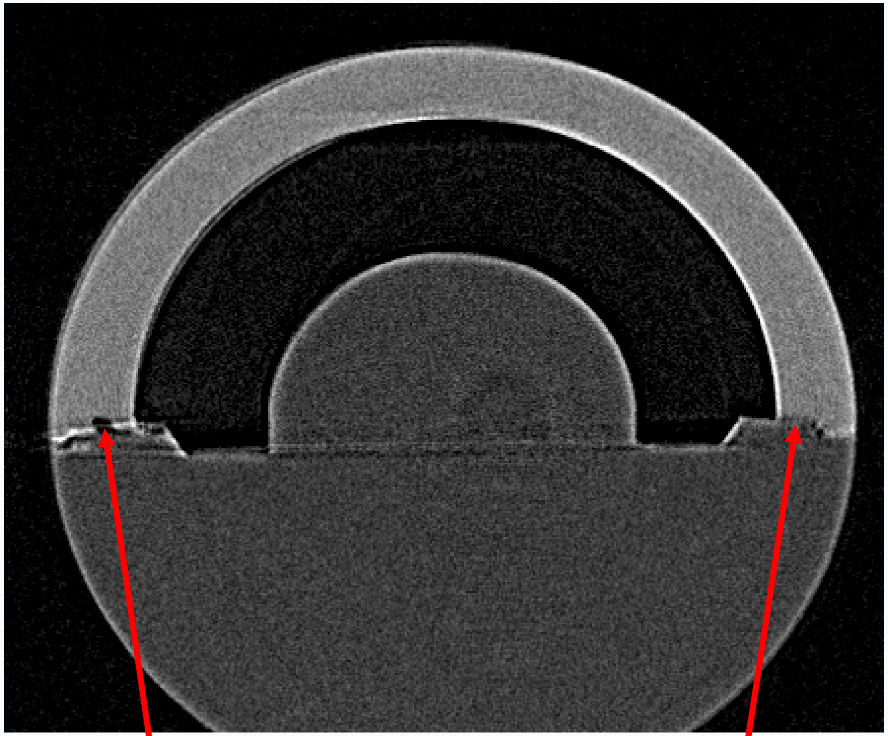


APS
% Transmission image (I/I_0*100)

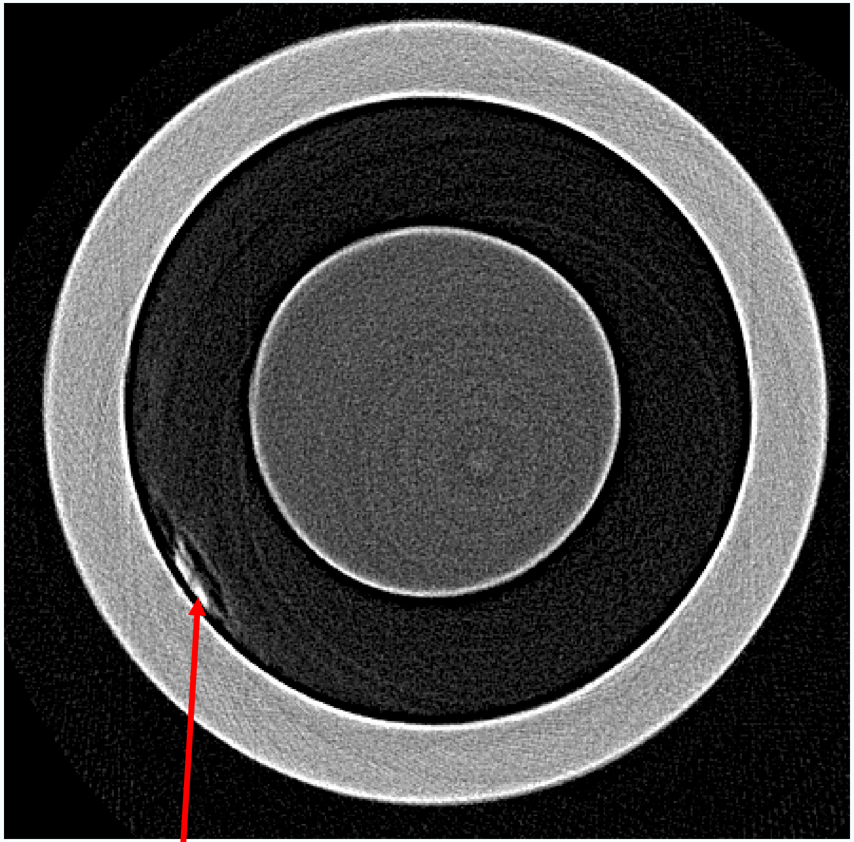


Computed tomography images from KCAT reveal internal features that can impact target performance

KCAT DATA
CT Slice through the X-Z plane



KCAT DATA
CT slice through the X-Y plane
Above step joint



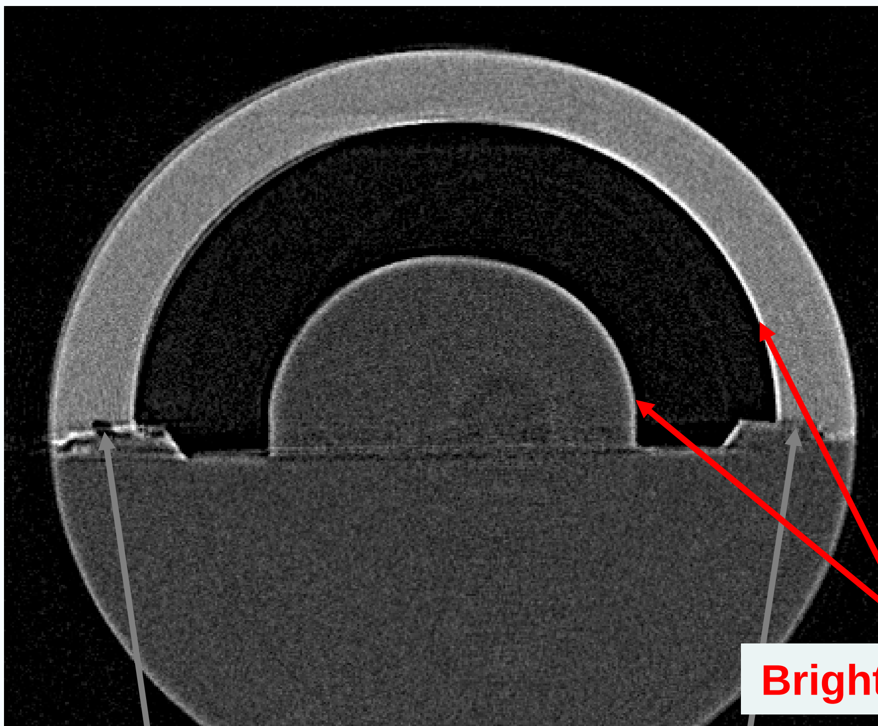
Air gaps are visible
Gaps seen in step joint

Better joint

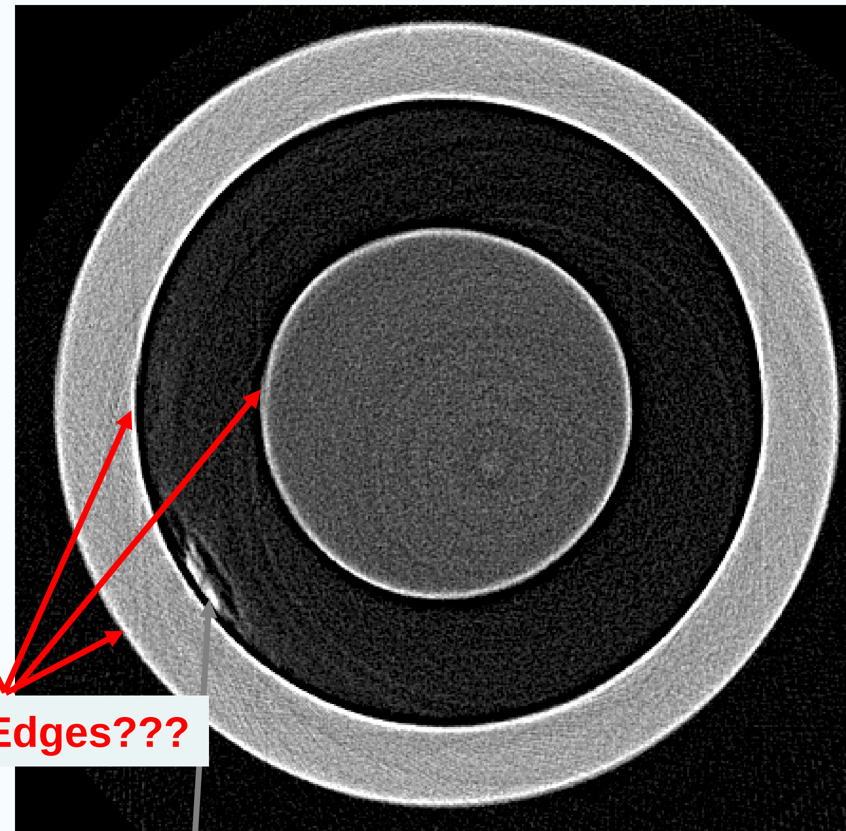
Excess glue material

Computed tomography images from KCAT reveal internal features that can impact target performance

KCAT DATA
CT Slice through the X-Z plane



KCAT DATA
CT slice through the X-Y plane
Above step joint



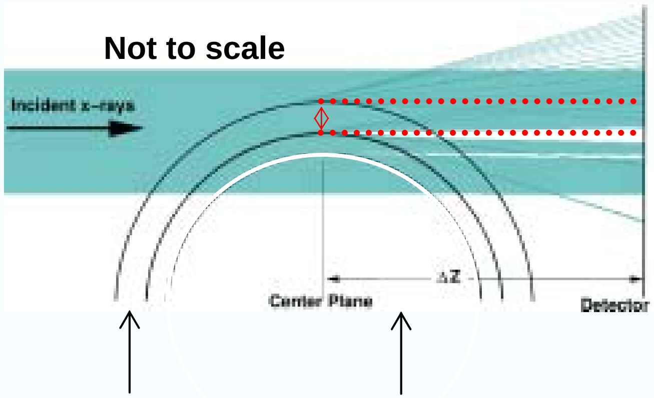
Bright Edges???

Air gaps are visible
Gaps seen in step joint

Better joint

Excess glue material

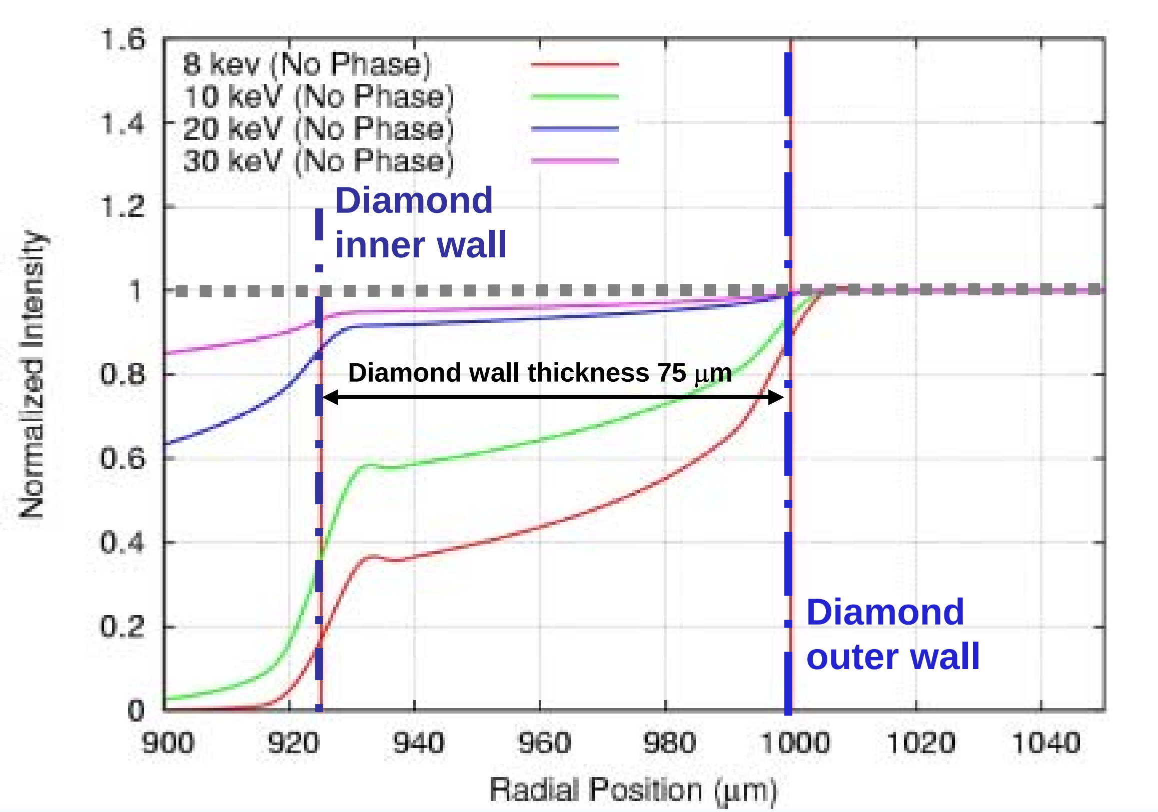
We need to quantitatively account for x-ray phase effects for accurate image analysis results



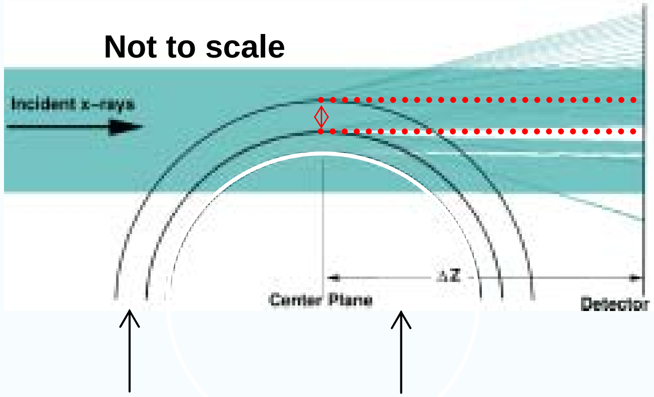
Diamond shell on Si_3N_4 mandrel

(1-mm radius, 75-μm wall diamond shell)

Simulation with only amplitude NO phase effects



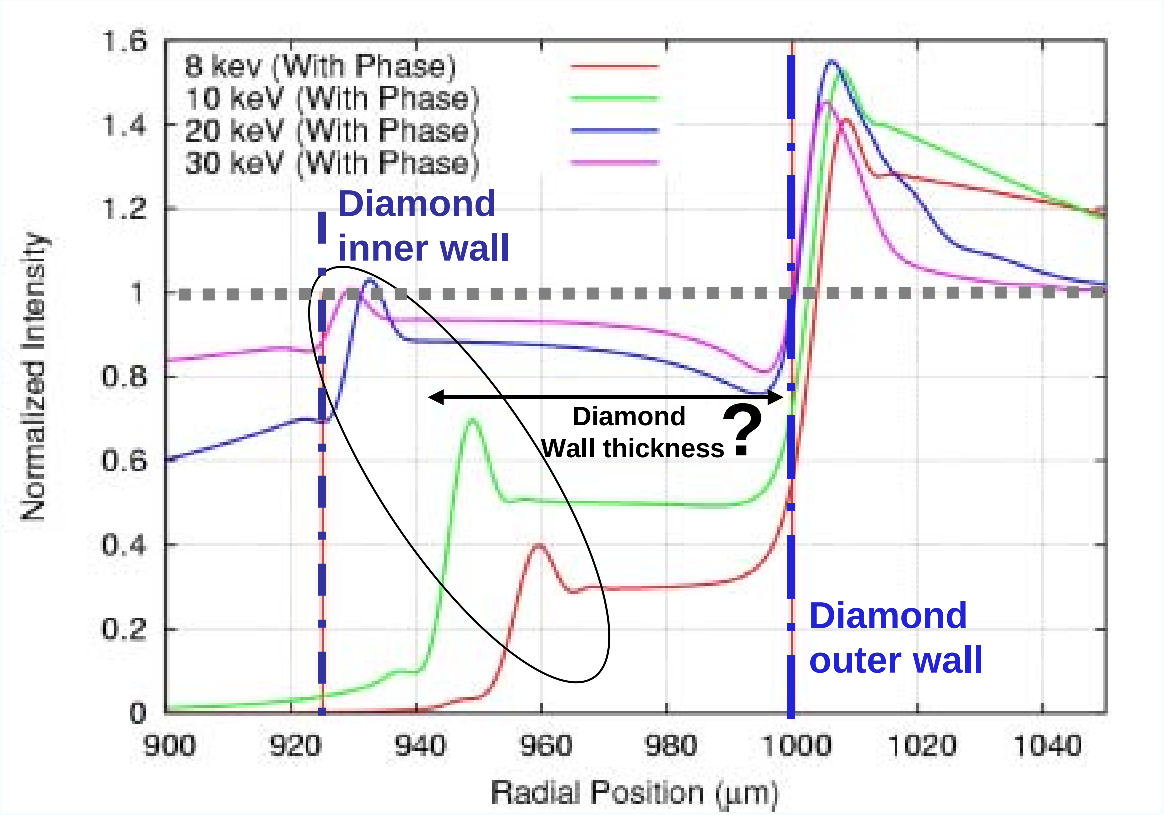
We need to quantitatively account for x-ray phase effects for accurate image analysis results



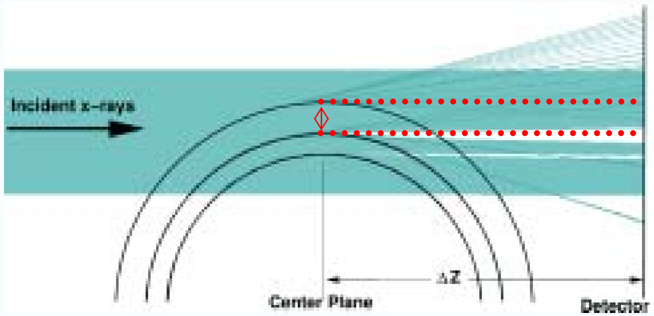
Diamond shell on Si_3N_4 mandrel

(1-mm radius, 75-μm wall diamond shell)

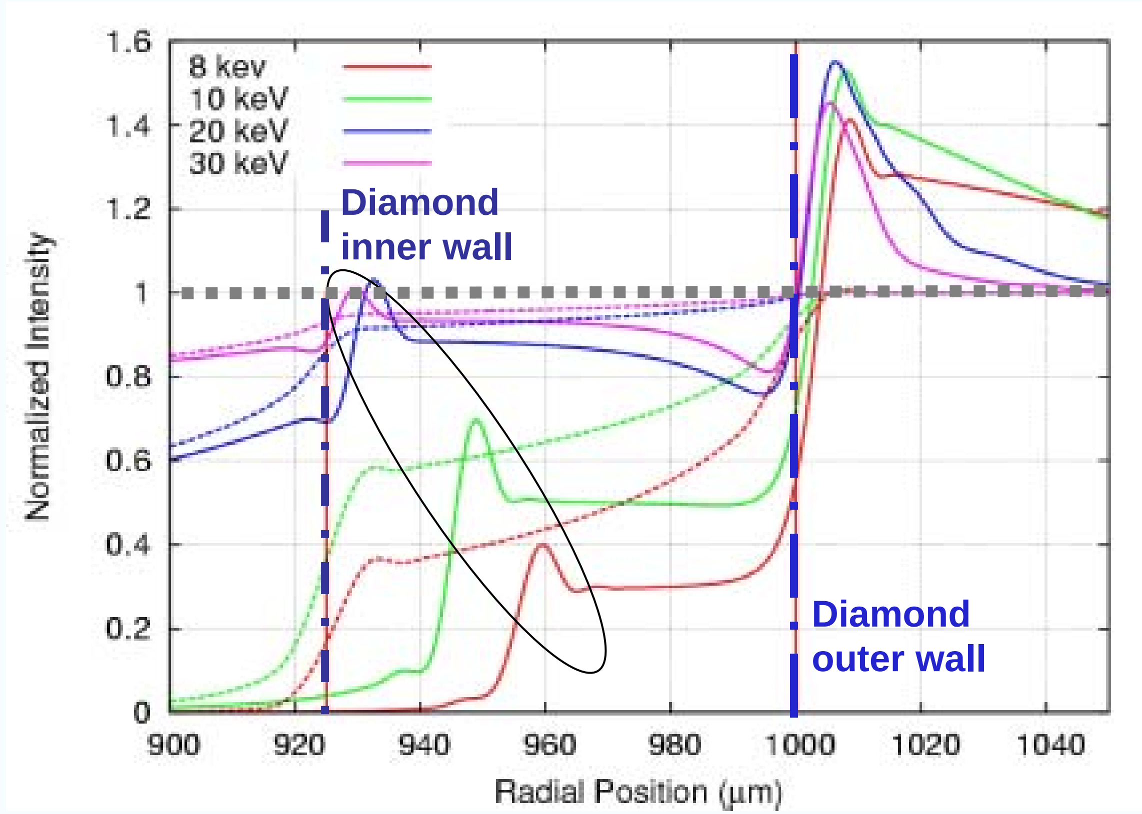
Simulation with amplitude and phase effects



We need to quantitatively account for x-ray phase effects for accurate image analysis results



Comparison with and without phase effects



Phase effects change with

- **Object materials & geometry**
- **Source-object-detector geometry**
- **Source energy**
- **Spatial resolution**

Phase effects can generate

- **Dimensional errors**
- **Fictitious gaps**
- **Wrong material identification**

Phase effects impact both radiographic and tomographic x-ray imaging

Comparison between synchrotron and lab x-ray sources

Synchrotron

- **Advantages**
  - High flux
  - Monochromatic
  - Tunable
  - Parallel beam
- **Disadvantages**
  - Expensive
  - Not Local
  - Low Availability
  - Non-uniform beam profile
  - Time varying beam
  - Limited energy range

Lab sources

- **Advantages**
  - Cheap
  - Local
  - High Availability
  - Uniform beam profile
  - Stable beam
  - Large energy range
- **Disadvantages**
  - Not brilliant
  - Polychromatic
  - Limited tunability
  - Non parallel
  - Spot size

Better sources—stable tabletop synchrotrons…???

Better detectors—high brightness, high-optical-quality scintillators…???